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A Customizable and Expandable Electroencephalography (EEG) Data Collection System

by Wosen Teraga Wolde and Joseph K Conroy

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A Customizable and Expandable Electroencephalography (EEG) Data Collection System

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14. ABSTRACT Electroencephalography (EEG), measuring the brain's electrical activity, has been used in many areas ranging from medical use to gaming and military applications. Devices used for EEG monitoring must have high accuracy and consistency to provide safe and reliable measurement of EEG for the specific application. This demands a device that can be customized or modified to how the data are collected and used to meet the requirement of that specific application. However, commercially available devices have been found to be limited in their customizability. This report presents the design, fabrication, and evaluation of an EEG test-bed that provides customizability and expandability. This EEG system is demonstrated to support high-bandwidth data sampling, real-time parameter updates, and wireless transmission.					
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Contents

List of Figures	iv
1. Introduction	1
1.1 Motivation	1
1.2 Overview	1
2. Design	2
2.1 Hardware	2
2.2 Software	3
2.2.1 User Interface	3
2.2.2 Device Interface	5
2.3 Expandability	5
3. Evaluation	6
3.1 Data Collection	6
3.2 Data Quality	6
3.2.1 Gain	7
3.2.2 Input-Referred Noise	8
4. Conclusion	9
5. References	10
Distribution List	11

List of Figures

Fig. 1	The EEG data collection PCB (left) and the ODRIOD-U3 computer (right)	2
Fig. 2	LabVIEW front panel with individual channel setting tab	4
Fig. 3	LabVIEW front panel with register configuration tab	5
Fig. 4	Test setup	6
Fig. 5	Measured output with gain = a) 1, b) 2, c) 12, and d) 24.....	7
Fig. 6	Measured input-referred noise	9

1. Introduction

There has been much interest in the past few decades in monitoring the brain's electrical activity, known as electroencephalography (EEG). Studies have shown encouraging results in the areas of medicine and gaming as well as toward military applications such as supporting human/robot interactions, developing mission-assisting devices, and monitoring physiological and behavioral activities of Soldiers to improve their health and safety.¹ Specifically, much interest is geared toward safe and reliable in situ EEG monitoring of Soldiers. A system to support this goal must also be highly customizable and permit data collection and real-time analysis.

The purpose of this report is to demonstrate the design, testing, and performance validation of an EEG data collection test-bed developed to support Army-specific applications. The EEG test-bed supports and provides high-bandwidth data sampling, real-time parameter updates, expandability, and wireless transmission. The performance of the integrated design is validated against component data sheet specifications.

1.1 Motivation

Bio-signals such as EEG are known to provide useful real-time information about human cognitive states.² Several companies offer commercial EEG measurement devices, including Emotiv Systems³ and Advanced Brain Monitoring,⁴ as well as open source alternatives such as OpenBCI.⁵ These products generally provide accurate and high-quality EEG data acquisition but have been found to be limited in their customizability needed to support research and advanced development. A custom solution was required to support expandability, modify the rate and size of data collection, and support future drop-in integration of a method for continuous electrode-to-skin impedance monitoring.

1.2 Overview

Measuring and recording the brain's electrical activities can be very challenging because the signals are very small in amplitude, in the range of millivolts down to microvolts, and inherent with the measurement of EEG are noise and artifacts.⁵ Generally, there is a large amount of interference and noise that may contaminate the desired signal when dealing with small signals. Because of the presence of such noise, EEG systems require a large dynamic range as well as high resolution, leading to the generally accepted usage of 24-bit data acquisition.²⁻⁴ Furthermore,

there are many methods suggested to mitigate noise and keep the sensed differential signals in the common-mode range, including varying the electrode considered to be ground and utilizing active current injection means such as a right leg drive.

2. Design

2.1 Hardware

The EEG data collection board is designed using the ADS1299 analog front end (AFE) (an 8-channel 24-bit analog-to-digital converter with a built-in programmable gain amplifier [PGA]) and a PIC18LF46K22T Microcontroller. The ADS1299 is a preferred choice for medical instrumentation devices because of its low-noise PGAs, high-resolution simultaneous sampling of 8 channels, and many other important features.⁶ The circuit is designed to allow access to the necessary features for this specific application.

The ADS1299 AFE handles the sample taking and the conversion of the analog signals to digital samples while the microcontroller handles the configuration of the ADS1299 and the data communication between the user, or the host computer, and the EEG board. Communication between the microcontroller and the host computer can be established in 2 ways. The first is serial communication using a Universal Serial Bus to transistor-transistor logic serial cables and the second is User Datagram Protocol over Wi-Fi using an ODROID-U3, a small 1.7-GHz Quad-Core processor and 2-GB random access memory Linux Computer. Figure 1 shows the EEG data collection printed circuit board (PCB) and the ODROID-U3 computer. The EEG board and the ODROID can be powered from one battery.

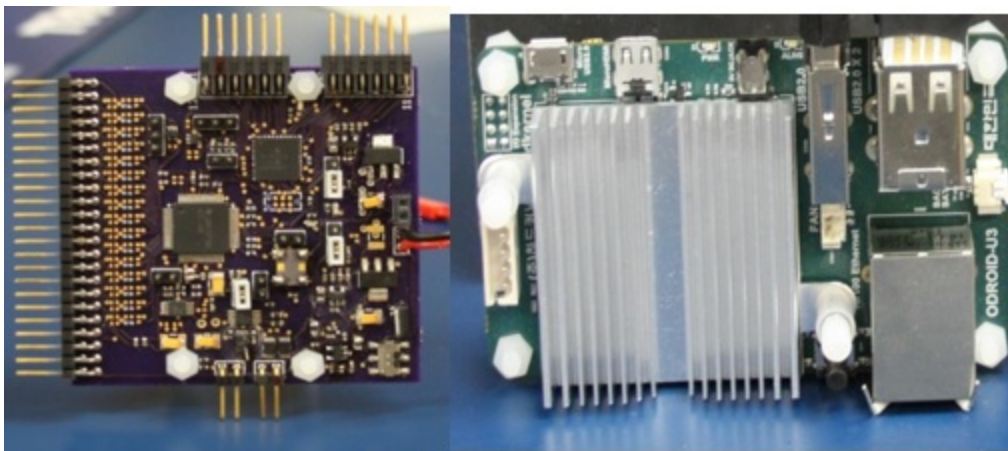


Fig. 1 The EEG data collection PCB (left) and the ODROID-U3 computer (right)

2.2 Software

2.2.1 User Interface

The EEG board has a user interface providing the user the ability to monitor the data, configure the ADS1299 AFE, and change any of the register settings at any time during the operation through software without having to connect or disconnect components. The user interface is written using a LabVIEW program with stand-alone applications (executables) that only require a LabVIEW Run-Time Engine to run on systems without LabVIEW installed. The program receives data from the system either through serial or UDP over Wi-Fi and displays the measured EEG data from the 8 input channels of the ADS1299. The user has the option to select the communication type, change the register settings of the ADS1299 to modify the measurement setup, and monitor the measured signals through the LabVIEW front panel. This program also allows the user to save the raw EEG data to a text file for further analysis.

The ADS1299 has many different configurations to perform accurate and consistent measurement. Some of the various features of the ADS1299 that the user may want to change to optimize performance are the gain, the sample rate, powering on/off individual channels, and enabling and disabling the lead-off detection feature that senses the connectivity of the electrode to the subject. These configurations are achieved by setting and clearing the specific register values of the ADS1299 AFE. The EEG board is designed to allow access to the source code of the microcontroller so the user can manipulate these register values through the LabVIEW interface to get the desired setting. When the system is turned on, the microcontroller programs the ADS1299 to a default configuration and the data acquisition and data transmission begins. The user can open and run the LabVIEW program from the host computer to start monitoring the recordings.

The LabVIEW front panel has 2 tabs from which the user can choose all the possible register settings. The first one is the Channel_Set tab (Fig. 2) used for configuring the individual settings of the 8 input channels and the second is the Config tab (Fig. 3) used for other register settings. These options can be modified to meet the required setting for a specific test. At any time during the operation, the user can change the register settings of the ADS1299 by selecting the available options for each register. The update button on the LabVIEW front panel sends the new settings to the microcontroller. When the microcontroller receives the update

information from the LabVIEW, it interrupts the current operation and reprograms the ADS1299 according to the new setting. Operation of the system with the new configuration resumes right after the update is performed.

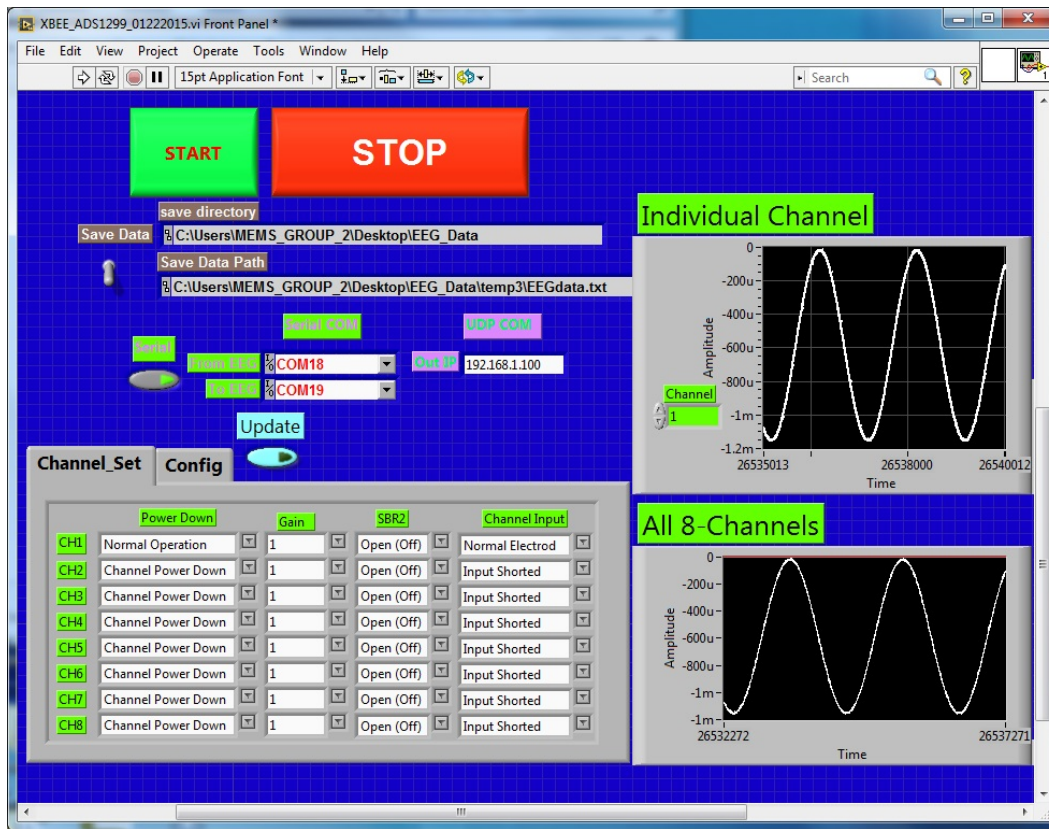


Fig. 2 LabVIEW front panel with individual channel setting tab

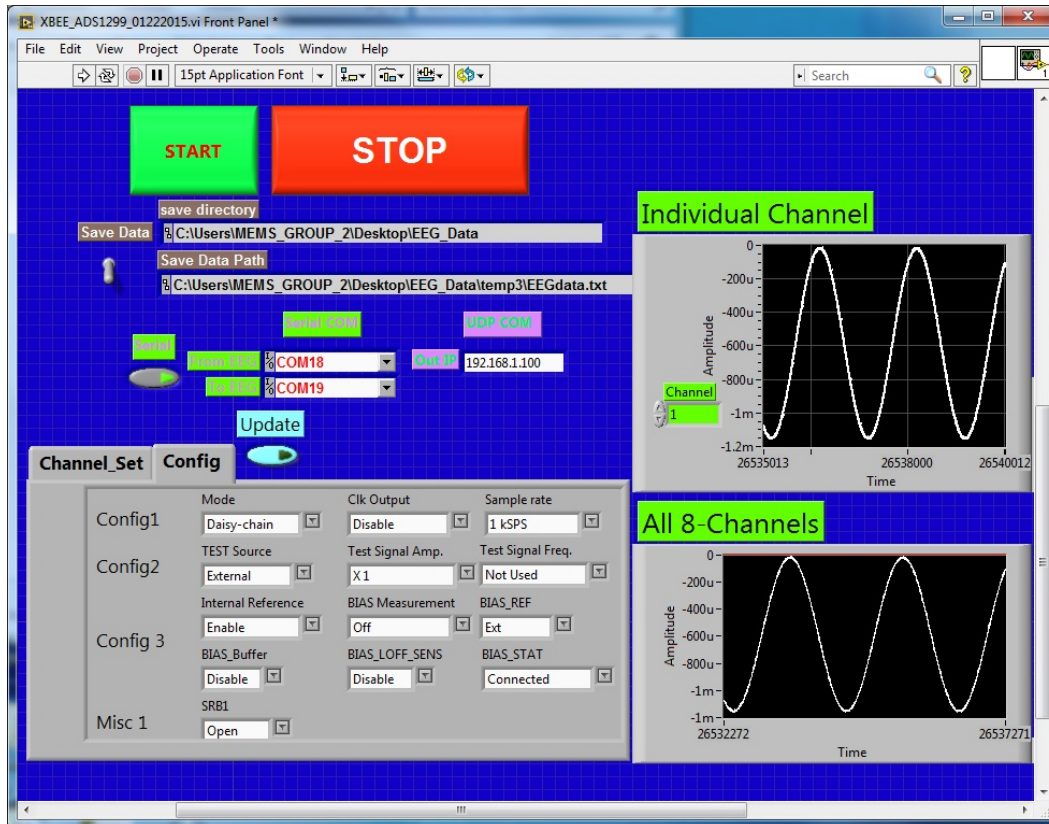


Fig. 3 LabVIEW front panel with register configuration tab

2.2.2 Device Interface

The EEG board transmits the data at a high rate to the host computer via UDP over Wi-Fi using the ODROID-U3 computer. A python program is written for the ODROID that establishes data communication between the EEG board and the ODROID and also broadcasts the data over Wi-Fi to the host computer.

2.3 Expandability

A single ADS1299 has 8 separate channels that can be measured simultaneously. Multiple ADS1299 AFEs can be cascaded together using the daisy-chain option to increase the number of channels. An expansion board, consisting of an ADS1299 AFE and a few external components, can be attached to the main board and add another 8 channels. These expansion boards share power supply connection and data transmission lines with the main board. Then by enabling the daisy-chain feature in the configuration register, the output data will be concatenated into one long serial bit-stream and read by the microcontroller. The number of expansion boards and the number of channels used are limited by the selected sample rate and data transmission rate of the data acquisition system.

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3. Evaluation

3.1 Data Collection

To validate the performance of the EEG board, a signal generator is used to generate simulated small test signals. Using test signals in the range of 20–100 μV in 0.5 to 50-Hz bandwidth, we were able to measure and recorded data from all 8 input channels of the EEG board through the LabVIEW program. The test setup of the EEG system is shown Fig. 4.

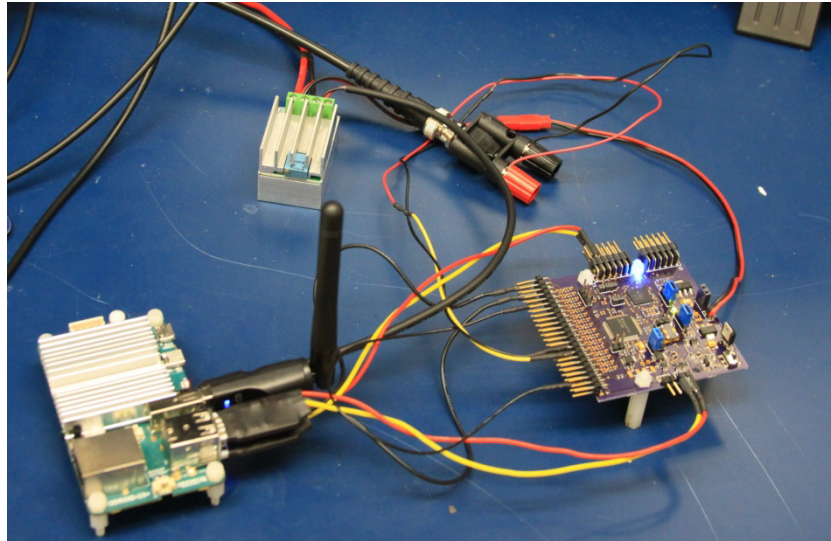


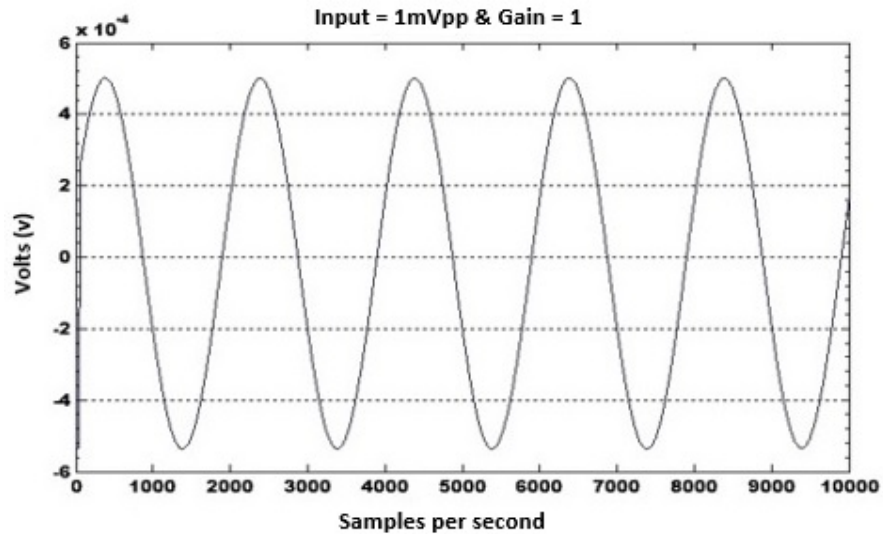
Fig. 4 Test setup

3.2 Data Quality

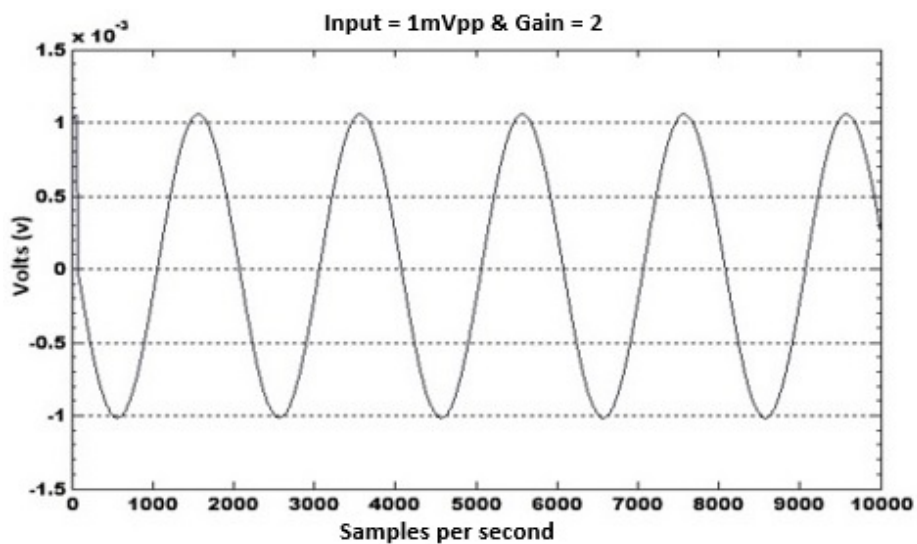
Along with the evaluation of the EEG data collection board, the other part of the test was to examine the operation of the ADS1299 AFE and verify some of the characteristics listed on the data sheet. The ADS1299 has many significant features that make it a preferred choice for EEG applications. The manufacturer provides the electrical characteristics of the AFE on the data sheet based on their assessment using their evaluation board. Even though the EEG data collection board was designed following the recommendation on the data sheet, performance of the AFE may not be the same from one circuit to another. Therefore, for verification purpose, the gain and the input-referred noise of the ADS1299 on the EEG data collection board were tested.

3.2.1 Gain

The ADS1299 has a built-in PGA with 7 different gain settings: 1, 2, 4, 6, 8, 12, and 24. The desired gain can be programmed using the individual channel settings register of the 8 input channels. A sine wave input voltage of 1 mVpp at 0.5 Hz was used to test the gain. With the sample rate set to 1 kHz, 4 measurements were taken with 4 gain settings of 1, 2, 12, and 24. The measured signals reflect the respective gain as shown in Fig. 5a–d. All 8 channels were tested and the results were the same.

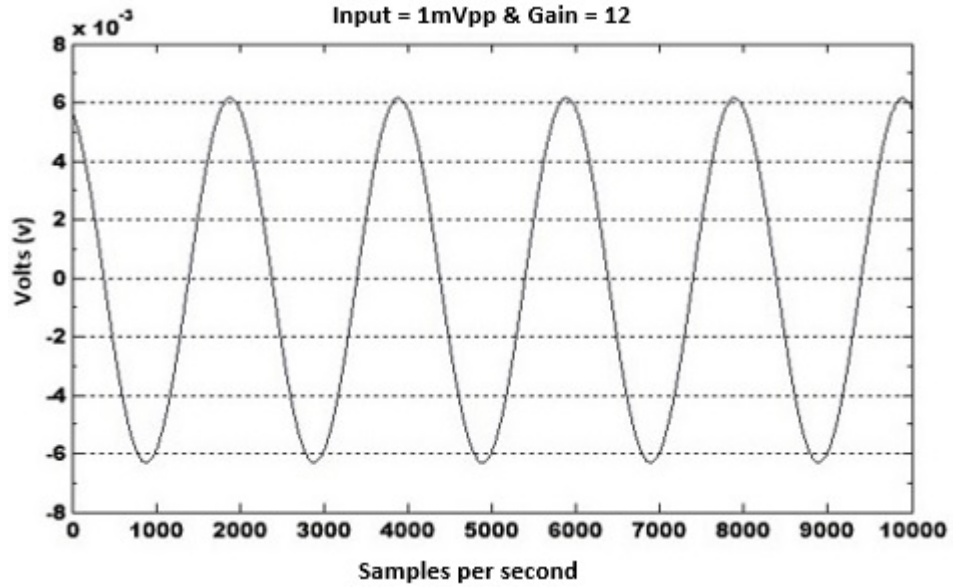


(a) Gain = 1

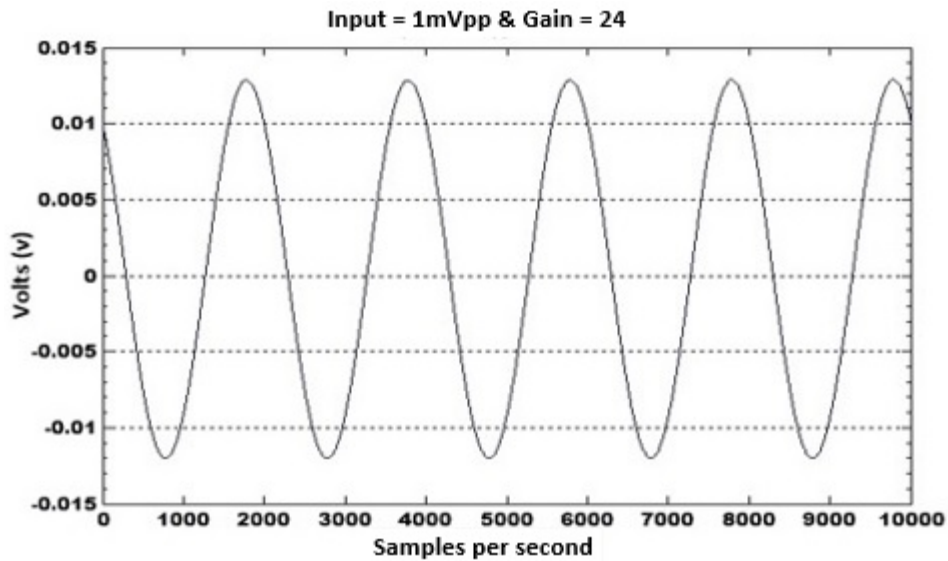


(b) Gain = 2

Fig. 5 Measured output with gain = a) 1, b) 2, c) 12, and d) 24



(c) Gain = 12



(d) Gain = 24

Fig. 5 Measured output with gain = a) 1, b) 2, c) 12, and d) 24 (continued)

3.2.2 Input-Referred Noise

The next verification test performed was the input-referred noise test. According to the data sheet, the ADS1299 has a very low input-referred noise, about $0.14 \mu\text{Vrms}$ with the sample rate set to 250 Hz and the gain set to 24. The ADS1299 on the EEG

board was also configured this way. All the positive and negative inputs of the 8 channels were tied together and connected to ground through the SRB2 pin of the ADS1299. We measured the output of all 8 channels, one at a time (Fig. 6). After removing the direct current offset and filtering out frequencies above 65 Hz, the noise level measured was $0.17 \mu\text{Vrms}$.

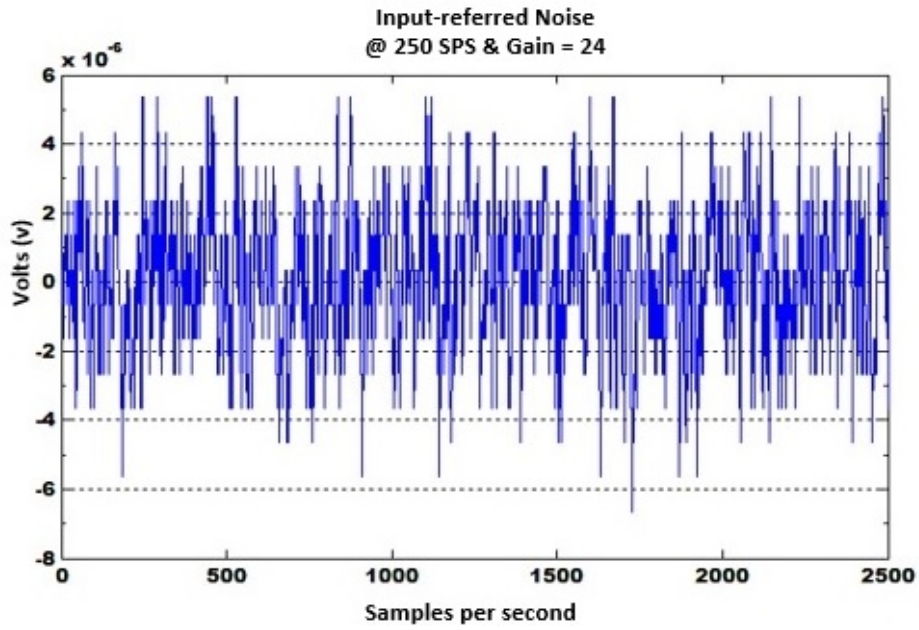


Fig. 6 Measured input-referred noise

4. Conclusion

The design, fabrication, and performance validation of an EEG data collection board is presented in this report. The verification tests using controlled inputs from a signal generator show that the board meets the requirements, which are to take accurate and high-quality measurement of small signals and to transmit data at a high rate for real-time update. In conclusion, the designed EEG board provides a platform for an EEG system with continuous electrode contact impedance monitoring and high-rate data update capabilities. Using the daisy-chain feature of the ADS1299, a number of these EEG boards can be connected together to increase the number of input channels. Future work includes the integration of the online impedance monitoring circuit onto the EEG board.

5. References

1. Evans G. Brain computer interfacing: a big step towards military mind-control. News, views and contacts from the global Army industry. London (UK): Army-technology.com. 2013 July 17 [accessed 2015 Mar 4]. <http://www.armytechnology.com/features/featurebrain-computer-interfacing-military-mind-control/>.
2. Mathews R, McDonald N, Anumula H, Trejo L. Novel hybrid sensors for unobtrusive recording of human biopotentials. In: Schmorrow DD, Stanney KM, Reeves, LM, editors. Foundations of augmented cognition: past, present, and future, 2nd ed. San Ramon (CA): Strategic Analysis, Inc and ACI Society; 2006. p. 91–101.
3. Emotiv. San Francisco (CA): Emotiv, Inc; c2011 – 2015 [accessed 2015 Mar 6]. <http://emotiv.com/>.
4. Advanced Brain Monitoring. Carlsbad (CA): Advanced Brain Monitoring, Inc.; c2000 – 2015 [accessed 2015 Mar 4]. <http://www.advancedbrainmonitoring.com/>.
5. OpenBCI. Open source brain-computer interface. Brooklyn (NY): OpenBCI; [accessed 2015 Mar 4]. <http://www.openbci.com/>.
6. Texas Instruments, Inc. ADS1299 data sheet: low-noise, 8-channel, 24-bit analog front-end for biopotential measurements. Dallas (TX): Texas Instruments, Inc; 2012 Jul [Revised 2012 Aug].

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